Stable massive particle in the ATLAS high-level muon trigger

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Summary

Trigger algorithms have been developed for detecting stable massive particles (SMPs) in the ATLAS detector.
The performance of the algorithms has been studied with Monte Carlo samples.
The algorithms can trigger SMPs with high efficiency in the region of β above 0.5

1. Introduction

ATLAS Experiment @ LHC

A multi-purpose detector, ATLAS, is designed to search for new physics.
It will start observing proton-proton collisions in 2009.

- A center of mass energy of 7 TeV for the initial running period
- bunch crossing time: 25 nsec
- luminosity of 10^{31} $cm^{-2}sec^{-1}$ for the initial running period

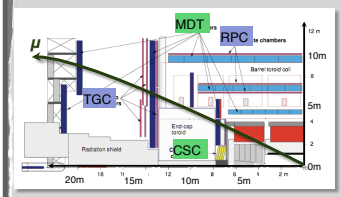
Stable massive particle (SMP)

✓ Some of Beyond the Standard Models (eg. SUSY, Extra dimensions) predict existence of ***"stable massive particle (SMP)"*** that might be produced at LHC and behaves as "***slowly-moving heavy muons***".

✓ If the velocity (β) and momentum (p) of a particle are measured, it is possible to calculate its mass to identify SMP.

$$m = p/\beta\gamma,\ (\beta = v/c,\ \gamma = 1/\sqrt{(1-\beta^2)})$$

ATLAS Muon Spectrometer



The ATLAS Muon Spectrometer consists of

✓ ***Three superconducting air-core toroid magnets***

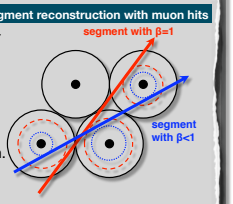
✓ ***MDT (Monitored Drift Tube)***
- measures hit positions of muon precisely in three stations.

✓ ***RPC (Resistive Plate Chamber) & TGC (Thin Gap Chamber)***
- muon trigger chamber
- RPC has good time resolution (1.5 nsec)

✓ ***CSC (Cathode Strip Chamber)***
- measures hit position of muon *in the extreme forward region.*

Muon Track Reconstruction

segment reconstruction with muon hits



✓ Muon track reconstruction includes finding segments in each MDT station. Segments are created using drift time information with assumption of traversing particle having β equal to 1.

✓ Muon track is reconstructed by fitting segments.

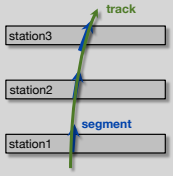
SMP Track Reconstruction

✓ An SMP travels slowly and arrival time at MDT is later than a muon.

✓ The drift radii of MDT for SMP track are mis-measured.
--> reconstructs good quality track by changing β.

ATLAS Trigger System

track reconstruction with segments



A three level trigger system reduces the final total event rate to about 200 Hz.

✓ ***Level1 trigger*** ***40 MHz --> 75 kHz***
- hardware trigger with calorimeter and muon information.

✓ ***Level2 trigger*** ***75 kHz --> 2 kHz***
- software trigger to confirm LVL1 trigger decision.
- processing time < 40 msec

✓ ***Event Filter (Level3 trigger)*** ***2 kHz --> 200 Hz***
- performs event selection using more complex algorithms
- processing time < 4 sec

Level2 trigger and Event Filter compose the High Level Trigger (HLT).

TrigMuonEF & TrigMuGirl

Algorithms to find muons and measure their momenta in the Event Filter.
We have developed new algorithms to measure β of slow particle.

2. SMP Trigger based on "TrigMuonEF"

TrigMuonEF

✓ An algorithm which performs muon identification and measures muon momentum ***"using hits in the muon spectrometer (MS) only"***

✓ uses LVL1 trigger information by RPC / TGC.

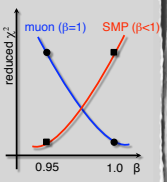
--> cannot reconstruct track with β less than 0.5 because RPC/TGC are not able to issue LVL1 trigger associated with the bunch crossing.

MuonBetaRefitTool

✓ MuonBetaRefitTool measures β and momentum of SMP candidates reconstructed by TrigMuonEF.

step1: Selection of SMP candidates

- compare reduced χ^2 of track reconstructed by TrigMuonEF and that of track refitted with β assumption of 0.95 using MuonBetaRefitTool.
- ***selects tracks satisfying the following condition:***
  reduced χ^2 (β = 0.95) - reduced χ^2 (β = 1.0) < 0.



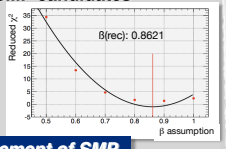
rejection power

	p_T = 10 GeV	p_T = 100 GeV	p_T = 200 GeV
total # of muons	5,364	6,702	6,654
β (rec) < 0.95	503 (9 %)	566 (8 %)	557 (8 %)

Fractions of muons identified as SMP candidates are 8 to 9 % regardless of p_T of muons.

step2: β Measurement of SMP candidates

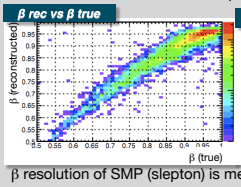
(1) refit track of SMP candidate changing β from 0.5 to 1.0 by 0.1 step.
(2) fit the reduced χ^2 distribution with parabolic function to find the minimum.



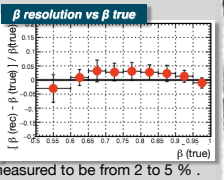
Performance of β measurement of SMP

We studied the performance of β measurement of SMP using Monte Carlo samples of Gauge mediated SUSY breaking (GMSB) model which have two stable massive sleptons in an event.

β rec vs β true



β resolution vs β true



β resolution of SMP (slepton) is measured to be from 2 to 5 % .

Background Rates @ 10^{31} $cm^{-2}sec^{-1}$

	Muon Backgrounds		
	p_T >= 10 GeV	pT >= 20 GeV	pT >= 40 GeV
generation	21.8 Hz	1,330 mHz	55.4 mHz
β (rec) < 0.95	2.0 Hz	106 mHz	4.4 mHz

We have estimated the rate of muon background from Standard Model processes (π/K, W, t, b, c) at the luminosity of 10^{31} $cm^{-2}sec^{-1}$.
--> Fake rate is negligible compared to EF rate of 200 Hz.

Processing Time

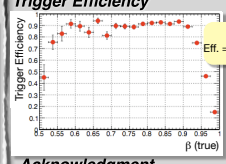
Processing time was measured with muons in $t\bar{t}$ sample.

		mean	rms
TrigMuonEFTrackBuilder	total time	193.6 msec	336.2 msec
	track reconstruction	110.7 msec	300.5 msec
	β measurement with MuonBetaRefitTool	82.6 msec	64.4 msec
MuonBetaRefitTool *(per track)*	total time	54.6 msec	56.0 msec
	processing time of 1st step	34.9 msec	11.1 msec
	processing time of 2nd step	131.7 msec	57.5 msec

CPU: Intel Xeon 5160 3.00 GHz

Reasonable processing time has been achieved by separating β measurement in two steps.

Trigger Efficiency



Eff. = # of tracks with β successfully reconstructed and matched with true SMP / # of true SMP passed LVL1 muon trigger

Trigger efficiency with MuonBetaRefitTool is 80 to 90% in β from 0.55 to 0.90.

Acknowledgment
MuonBetaRefitTool has been developed in consultation with ***Niels van Eldik (University of Massachusetts)***

3. SMP Trigger based on "TrigMuGirl"

SMP trigger flow with TrigMuGirl

... → **LVL2 trigger** selects SMP candidates → **TrigMuGirl** **StauTool** measures β of SMP → ...

SMP candidate Selection @ LVL2

✓ select SMP candidates ***with p_T > 40 GeV, β < 0.97 and Mass > 40 GeV*** at LVL2 using the TOF measured by the RPC.

SMP candidate Selection @ EF (TrigMuGirl)

✓ TrigMuGirl extrapolates inner tracking detector (ID) tracks to MS, looks for hits in MS, and creates segments using these hits.

✓ Fit ID track and segments in MS to identify muon track.

✓ In order to detect Charge flip R-Hadrons, If there is a LVL2 muon feature in the MS without a matching ID track, it starts from the LVL2 muon.

✓ ***The SMP processing uses the muon hits found by TrigMuGirl.***

StauTool

✓ StauTool measures β of SMP candidate in TrigMuGirl as follows.

step1: Select range for the minimization process

- create segments with the muon hits associated to ID tracks changing β assumption between 0.2 to 1.2 by 0.1 steps.
- In the barrel, restrict the range to an area close to the minimum of the RPC χ^2.
- selects the range where the MDT segment maker uses the same hits for the segments.

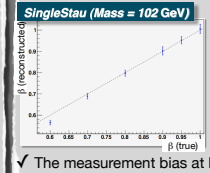
step2: Perform the minimization process in the selected range

- Find the β where χ^2 of muon segment is minimum with the golden section method.
  The χ^2 calculation of segment is different in different part of the detector.
  - In the endcap region, it minimizes the χ^2 of the MDT segments
  - In the barrel region, it minimizes the χ^2 of the MDT segments together with RPC time measurement.
- Refit ID track and hits in MS using the estimated β.
- ***Selects SMP candidates which have p_T > 20 GeV, β < 0.97 and Mass > 40GeV.***

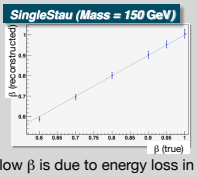
Performance of SMP trigger with TrigMuGirl

β measurement of SingleStau

SingleStau (Mass = 102 GeV)



SingleStau (Mass = 150 GeV)



✓ The measurement bias at low β is due to energy loss in the calorimeters.

✓ The bias is less significant in higher masses because the relative energy loss in the calorimeters is smaller.

Background Rate @ 10^{31} $cm^{-2}sec^{-1}$

The background is almost entirely from high p_T muons.

Muon Source	10^{31} rate (mHz)
$c\bar{c}\rightarrow\mu X$	2.4
$b\bar{b}\rightarrow\mu X$	1.6
$W\rightarrow\mu\nu$	0.4
$t\rightarrow b\mu\nu$	< 0.1
$z\rightarrow\mu\mu$	< 0.1
total	4.6

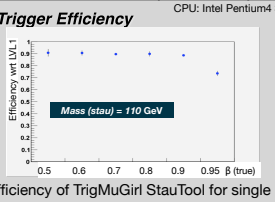
Processing Time

Processing time was measured with muons in $t\bar{t}$ sample.

	mean	rms
total time	39.9 msec	22.8 msec
Level 2 stau selection	3.9 msec	0.5 msec
Muon Reconstruction at EF	124.3 msec	74.9 msec
StauTool at EF	138.2 msec	87.5 msec

CPU: Intel Pentium4 3.00GHz

Trigger Efficiency



✓ Efficiency of TrigMuGirl StauTool for single stau events passing the LVL1 trigger.

✓ The efficiency drop at β = 0.95 is due to the selection cut of β < 0.95.

Acknowledgment
The SMP trigger with TrigMuGirl was written by
S. Tarem, S. Bressler, S. Vallecorsa, Y. Tenebaum Katan (Technion Univ.)

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